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THE CANTED TURNSTILE AS A OMNIDIRECTIONAL SPACECRAFT ANTENNA SYSTEM

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THE CANTED TURNSTILE AS A OMNIDIRECTIONAL SPACECRAFT ANTENNA SYSTEM

INTRODUCTION

Spin stabilized satellites will usually require an omnidirectional type antenna system since their aspect is continually changing as viewed from earth. The turnstile antenna or a variation of it is a simple, practical, system for this purpose. This paper will discuss the operation of turnstile antennas on structures noticeable in terms of wavelength. Some examples of spacecraft applications will be detailed.

Description of the Flat Turnstile Antenna

The normal turnstile antenna consists of two half wave length dipoles mounted at right angles to each other. In the spherical coordinate system (see Figure 1) these elements would lie in the $\theta = 90°$ (equatorial) plane. The dipole pairs are excited such that they are phased 90 electrical degrees apart. Viewed from the $\theta = 0$ axis the $\bar{E}$ vector will be seen to rotate progressively and complete one rotation for each period of the applied signal. Measuring with the optimum polarization in each case the signal level varies from +2dbI along the θ axis to -1dbI in the $\theta = 90°$ plane.

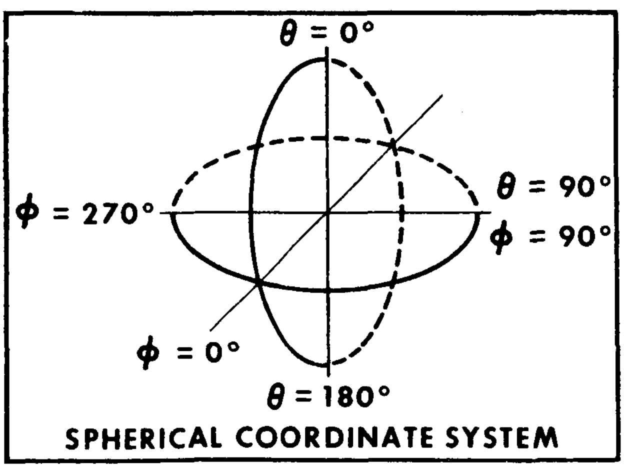


Figure 1–Spherical Coordinate System

Polarization – Definition

If at a fixed position on the field (θ) axis the resultant electric field vector $\bar{E}$ is constant in magnitude and rotates uniformly with time in the $\theta = 90°$ plane, completing one revolution each cycle, the wave is said to be circularly polarized. The sense of circularity is defined by looking in the direction of wave travel. If the receding wave rotates in a clockwise direction the polarization is defined to be right hand circular. If the direction of rotation is counter-clockwise the wave polarization is defined as left-hand circular. (IRE STANDARDS DEF).

If the locus of the tip of the $\bar{E}$ vector describes an ellipse rather than a circle the wave is described as elliptically polarized. The special case of linear polarization occurs when one axis of the ellipse is zero and the locus of the E vector is in a plane parallel to the direction of travel. (Figure 2).

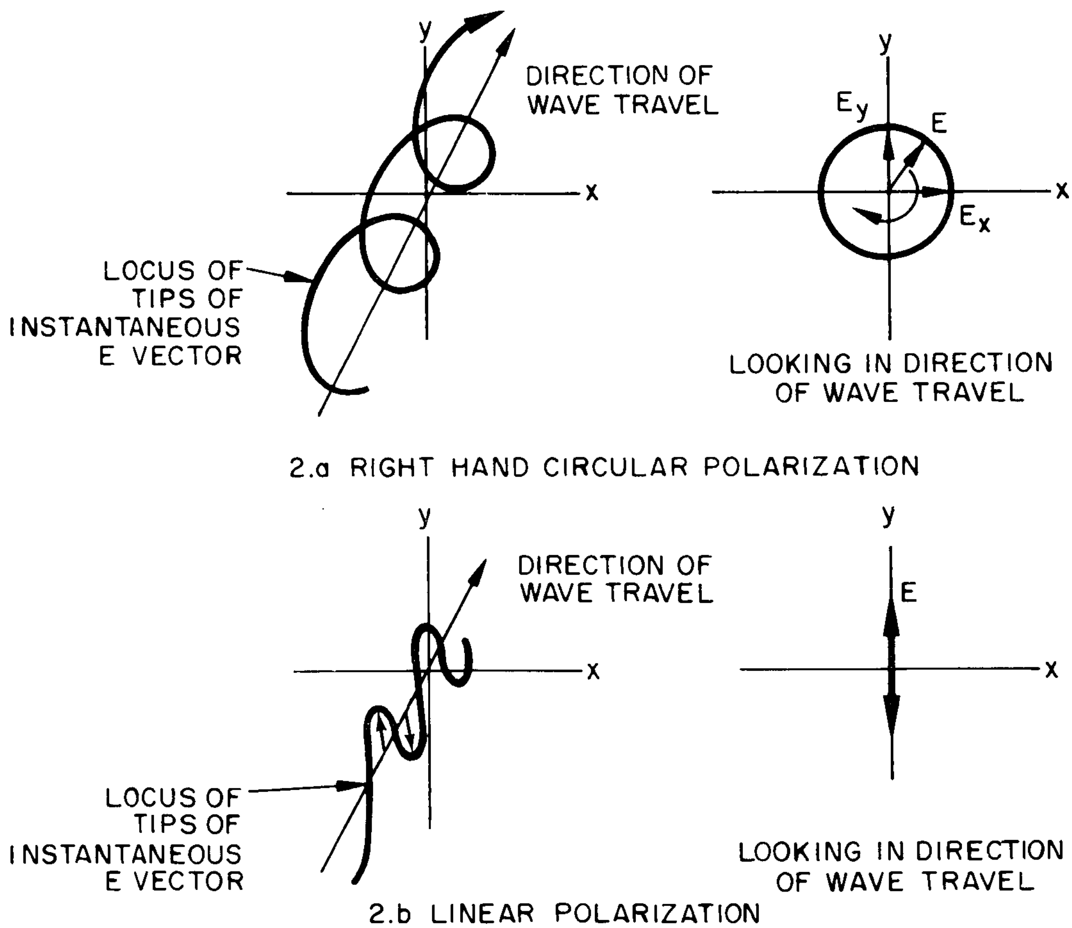


Figure 2–Wave Polarization

Polarization Characteristics of the Flat Turnstile

The flat turnstile antenna radiates circular polarization along the θ axis. The sense of the circularity is opposite along the $\theta = 0$ axis to that along the $\theta = 180°$ axis. Moving from the point $\theta = 0°$ toward $\theta = 90°$ the polarization becomes elliptical with its limit as linear polarization lying in the $\theta = 90°$ plane. The polarization would then become elliptical of the opposite sense and become circular at $\theta = 180°$.

Canted Turnstile

Description

The canted turnstile is formed from four monopole antennas approximately one quarter wavelength long. The bases of the antennas are usually separated by some distance (d) and the antennas are tilted at an angle (α) to the plane containing the bases (Figure 3).

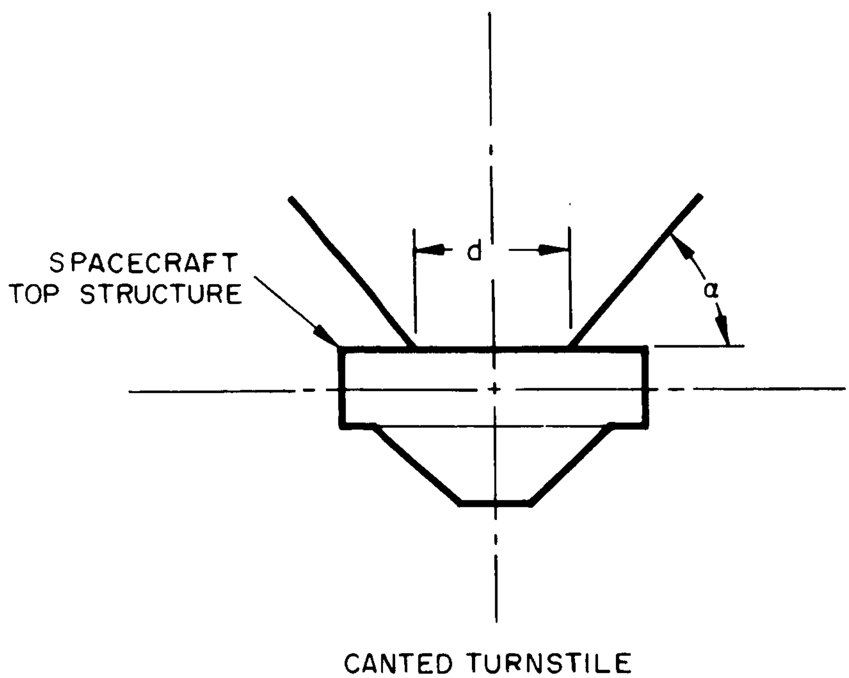


Figure 3–Canted Turnstile

Reasons for Using the Canted Turnstile Antenna on a Spacecraft

In any antenna array the relative spacing of the individual elements is very important. The reason for this is that the path length difference between various elements will change according to aspect (Appendix). It is this property that is used to form directive arrays. Since the turnstile is designed to be omnidirectional the separation between elements must be a minimum.

Usually a spacecraft structure is comparatively large in terms of the wavelength used. This forces a separation of the bases of the monopoles. By using a canted turnstile on a flat surface symmetric to the spin axis the base separation may be minimized. This will usually provide much better coverage and a smoother pattern as the satellite rotates.

The canted type antenna will also fit into most vehicle shroud compartments without folding. This increases the reliability of the system.

Polarization Characteristics of the Canted Turnstile Antenna

The radiation characteristics of the canted turnstile antenna in free space are similar to those of the flat turnstile with the following qualifications. The radiation is circular along the θ axis and is linear in the $\theta = 90°$ plane. But instead of the linear polarization vector being parallel to the $\theta = 90°$ plane it will be at some angle δ to the $\theta = 90°$ plane (Figure 4) δ will depend on the angle of the antenna elements (α) and on their base separation (d). (Figure 3).

On a large spacecraft structure with solar paddles, experiment booms, etc., linear polarization may no longer lie in the $\theta = 90°$ plane.

The position at which linear polarization occurs may vary from $\theta = 45°$ to $\theta = 110°$. The angle of the linear polarization and its position may also vary with rotation about the spacecraft axis. The consequence of this property is that although the radiation in the aspect $\theta = 45°$ to $\theta = 110°$ is predominately linear polarized it is difficult to predict the polarization angle. A circularly polarized or diversity polarized linear system would therefore be recommended for reception of signals from this aspect.

Effects of Spacecraft Size and Structure on Antenna Pattern Shape

Any spacecraft of dimensions relatively large in terms of the wavelength used will affect the pattern of antennas mounted on its surface. The problems associated with an omnidirectional pattern coverage are different from those encountered for a directional antenna system. The directional pattern places

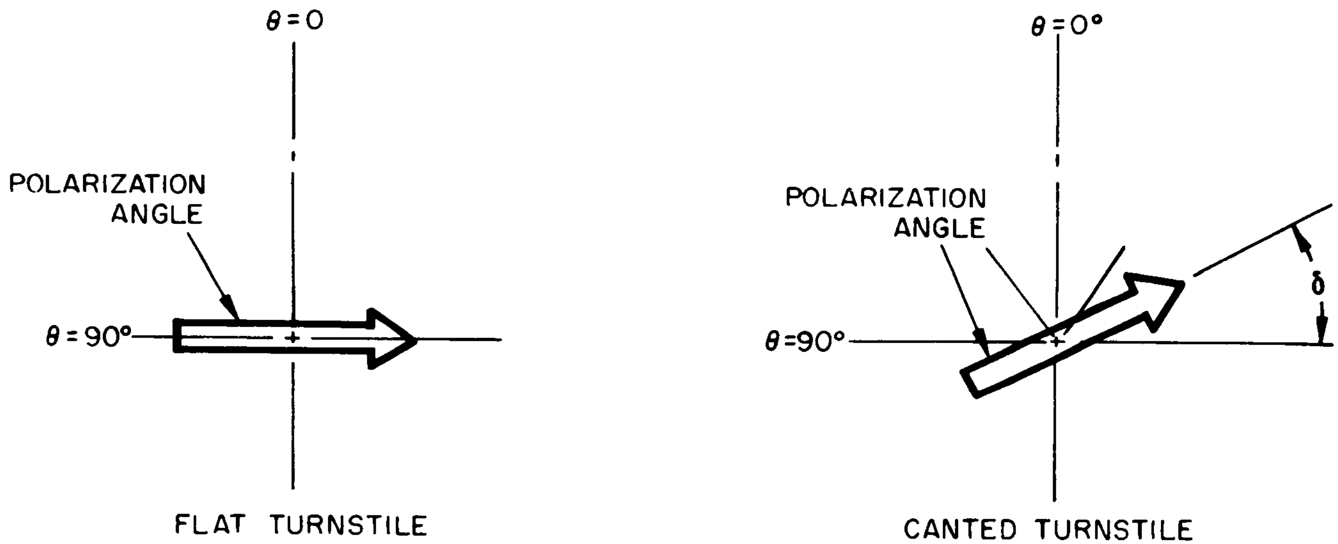


Figure 4–Polarization Angles

more stringent requirements on parts of the system, but since the antenna pattern desired is concentrated in one direction the portions of the spacecraft away from the beam are not as critical. For an omnidirectional system the entire structure must be considered, but small pattern anomolies due to structure which might be unacceptable to a directive array may be tolerated.

Some examples of spacecraft systems using the canted turnstile are given at the end of this paper. The spacecraft have varied from about a quarter to nearly a half wavelength in diameter.

On spacecraft of this size the body of the spacecraft has a directive effect. That is the pattern maximum occurs on the axis away from the antennas.

A good example of this is the AE-B satellite (Figure 12) which has an 8 db stronger signal on the axis away from the antennas.

When the structure size is increased, for example with large solar paddles the spacecraft will then act as a reflector or ground plane. On the IMP-E (Figure 9) spacecraft, the body alone showed a pattern maximum of +2 dbi in the $\theta = 180°$ direction. When the solar paddles were added the maximum of +2 dbi occurred in the $\theta = 0°$ direction.

In general solar paddles and other large flat surfaces act as reflectors. Usually experiment booms and inertia booms will affect the signal polarization and phase shift more than they affect the total radiation pattern.

The antenna patterns are half-patterns in the plane of $\phi =$ const. The complete pattern would be symmetric to the $\theta = 0$ axis.

Examples

The canted turnstile system has been used on a number of satellites in the Goddard Space Flight Center program. Several different methods of feeding the system have been used. It can be seen from the patterns that the angle of the antenna rods (α) does not greatly change the patterns. Some examples of various feed systems and antenna configurations will be discussed.

A. Ariel I (Figure 5)

Antenna:	Canted turnstile
d:	15"
α:	45°

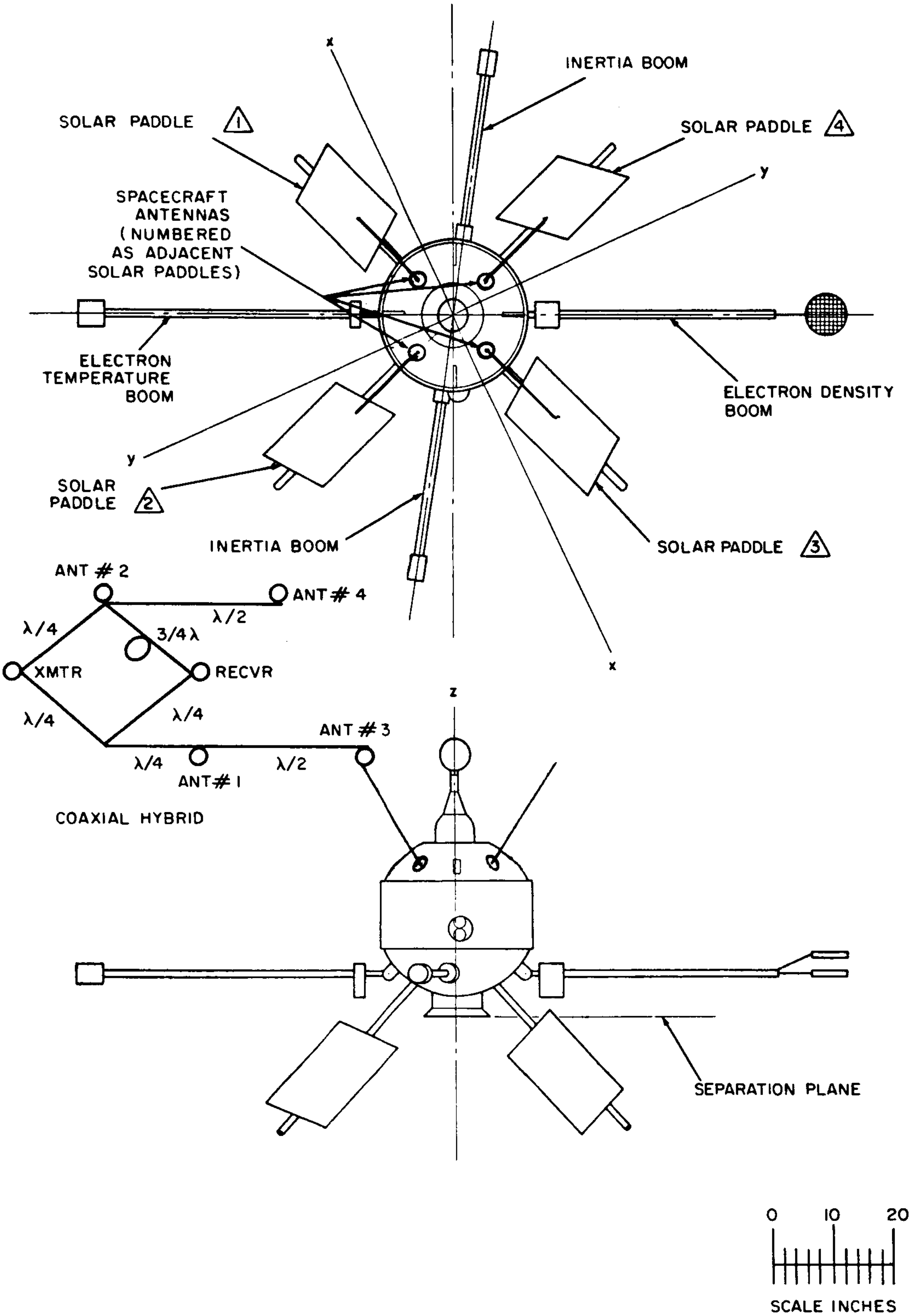


Figure 5—Ariel I Satellite

Feed:	Diamond hybrid 3 legs $\lambda/4$ one leg 3 $\lambda/4$ 136 MHz
Phasing:	$\lambda/4$ coaxial line
Freq:	Transmit 136 MHz
	Receive 123 MHz
Performance:	The pattern is generally omnidirectional The transmitter polarization is left-hand circular in the $\theta = 0$ direction and right hand circular the $\theta = 180°$ direction.
Antenna Gain:	$\theta = 0° = +3$ dbi
	$\theta = 90°$ -1 dbi
	$\theta = 180°$ - 4 dbi

The coaxial hybrid provides an equal power split and the two outputs are either in phase (from the transmitter input) or 180° out of phase (from the receiver input). To get the necessary 90° phase shift, a quarter wavelength of 50 ohm coaxial cable is used on one ouptut. Each antenna is matched to 100 ohms and the opposite pairs are connected by a half wavelength of 50 ohm coaxial cable. This provides an effective impedance of 50 ohms at the hybrid output ports. The hybrid itself is constructed of 70 ohm coaxial cable in order to present a 50 ohm impedance at the transmitter and receiver ports. Since the transmitter and receiver are on opposite sides of the hybrid the respective phase shifts at the output are reversed. This means that at $\theta = 0$, for instance, left hand circular polarization is transmitted and right hand circular is received.

Drawbacks to the coaxial hybrid system are its narrow bandwidth, multiple cable connections and slightly more loss in the extra length of cable in the 3 $\lambda/4$ leg. The 90° phasing line is only accurate at the tuned frequency, therefore at the receiver frequency the phasing is about 10% off.

Spacecraft IMP-F (Explorer 34) (Figure 6)

Antenna:	Canted turnstile
d:	14"
α:	65°
Feed:	Coiled coaxial hybrid

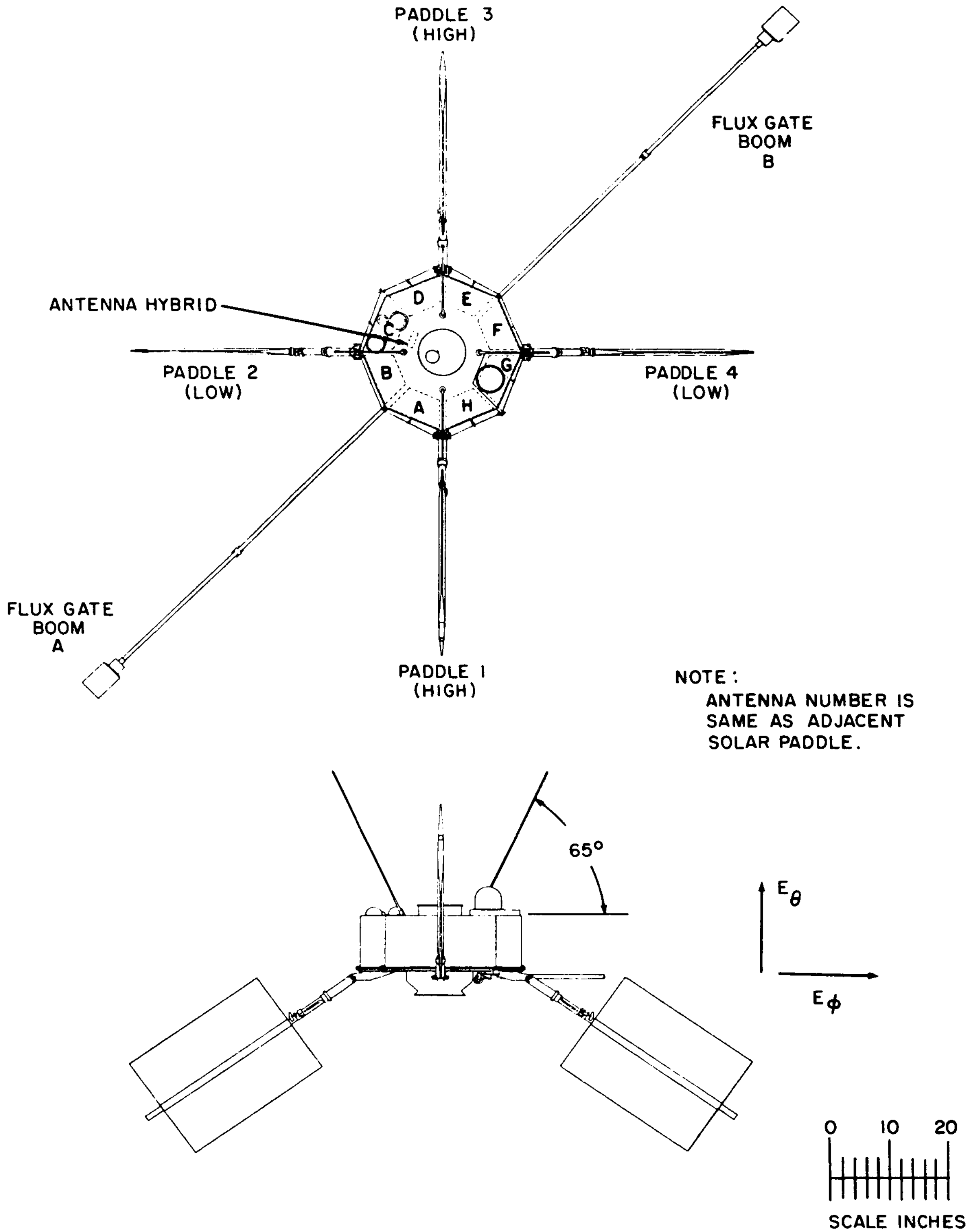


Figure 6—Explorer 34 Satellite

Phasing:	$\lambda/4$ coaxial line
Frequency:	136 MHz transmit
	146 MHz receive
Performance:	Omnidirectional pattern, left hand circular at $\theta = 0°$
	Right hand circular at $\theta = 180°$ (transmitted)
Antenna Gain:	$\theta = 0°$ +2 dbi $\theta = 90°$ -1 dbi $\theta = 180°$ -2 dbi

Typical patterns are shown in Figure 8. Levels shown are average and may have individual peaks and valleys of 5-6 db.

The coiled coaxial hybrid is formed from four 70 ohm quarter wavelength coaxial cables. The cables are wound into helical chokes to prevent radiation or loss from the cable shields. One cable has the center conductor grounded and the shield connected to the center conductor of its mating cable. This provides a wide band 180° phase shift between the two sides of the hybrid and allows the input signals to be out of phase and cancel at port B (Figure 7). The hybrid is quite wideband and will have less loss than the standard coaxial type. Phasing is accomplished by a $\lambda/4$ cable at the transmitter frequency. This length is about 10% long at the receiver frequency.

<u>IMP-E (Explorer 35) Figure 9</u>

Antenna:	Canted turnstile
d:	17"
α:	15°
Feed:	90° 3 db stripline coupler
Phasing:	Provided by coupler
Frequency:	Transmit 136 MHz
	Receive 148 MHz
Performance:	Omnidirectional pattern right hand circular at $\theta = 0$,
	left hand circular $\theta = 180°$ (transmitted) (Figure 11).

The 90° coupler is of the Shimizu type (Figure 10). It is formed by two $\lambda/4$ stripline circuits separated by a thin layer of dielectric. The operation of the coupler assures an equal power split and provides an automatic 90° of phase shift at both frequencies. The coupler is a very low loss device and the wideband operation assures better isolation and improved patterns at the receiver frequency. Some typical patterns are shown (average values in θ).

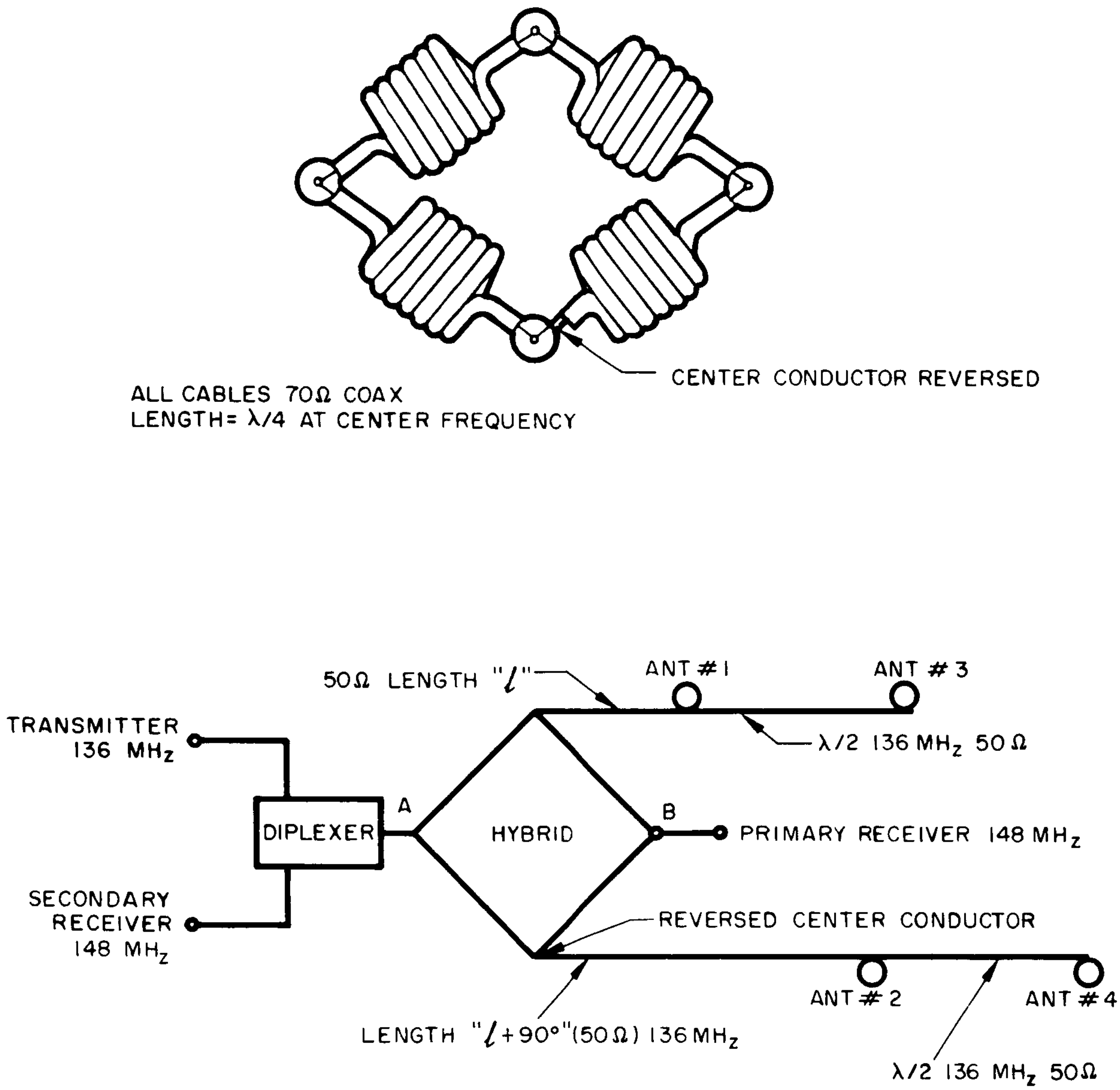


Figure 7–Explorer 34 Feed System

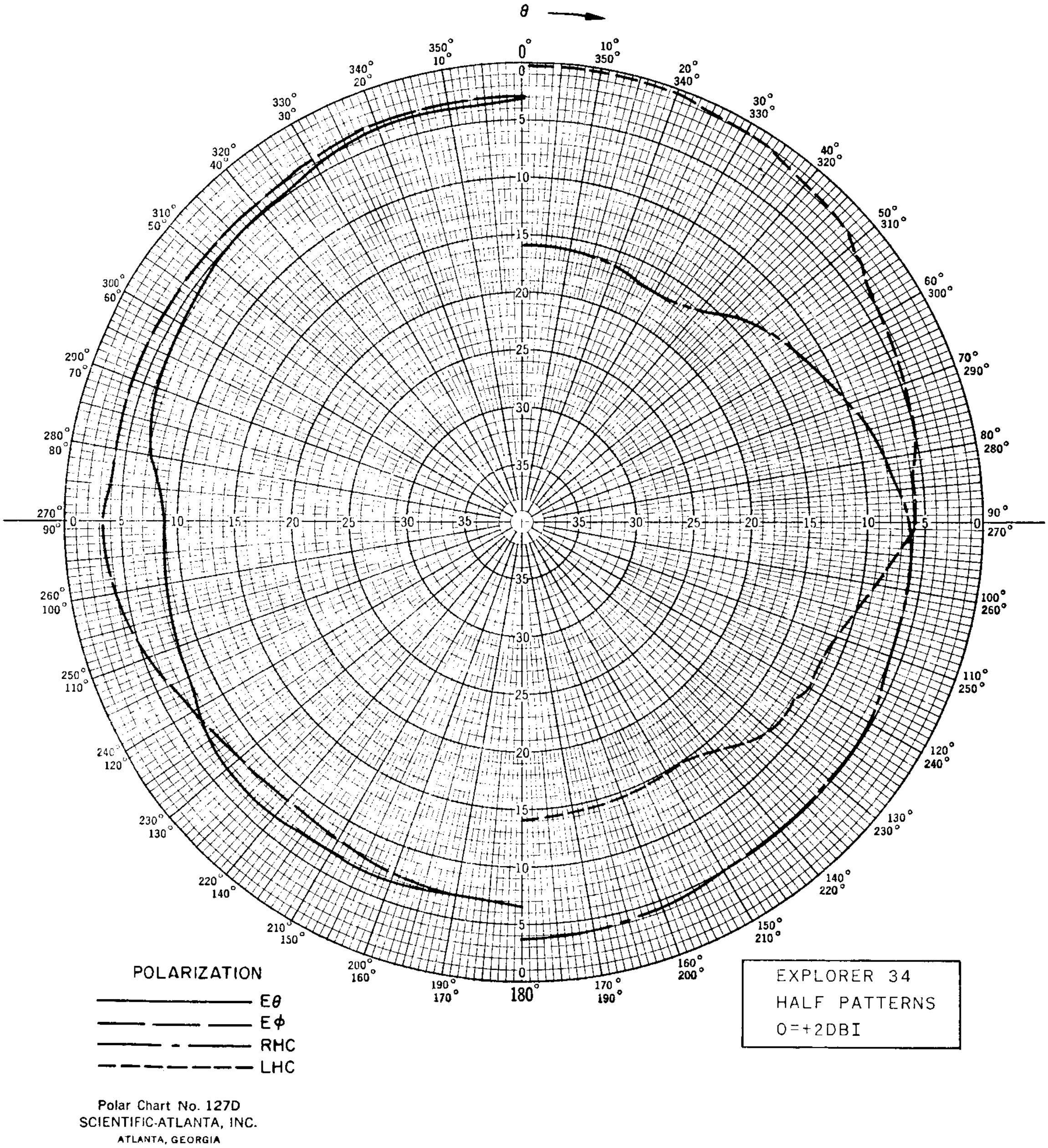


Figure 8—Explorer 34 Antenna Pattern

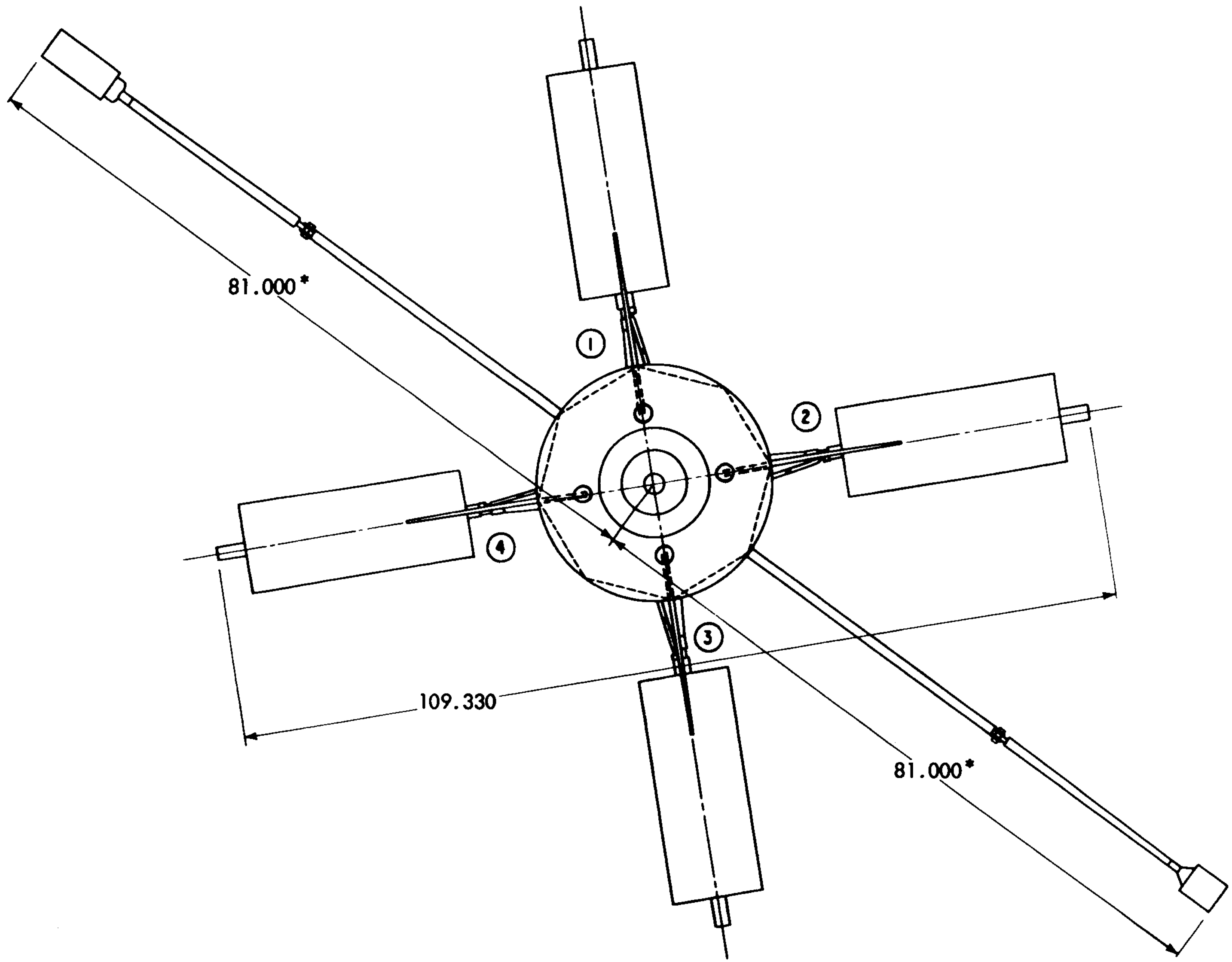


Figure 9—Explorer 35 Satellite

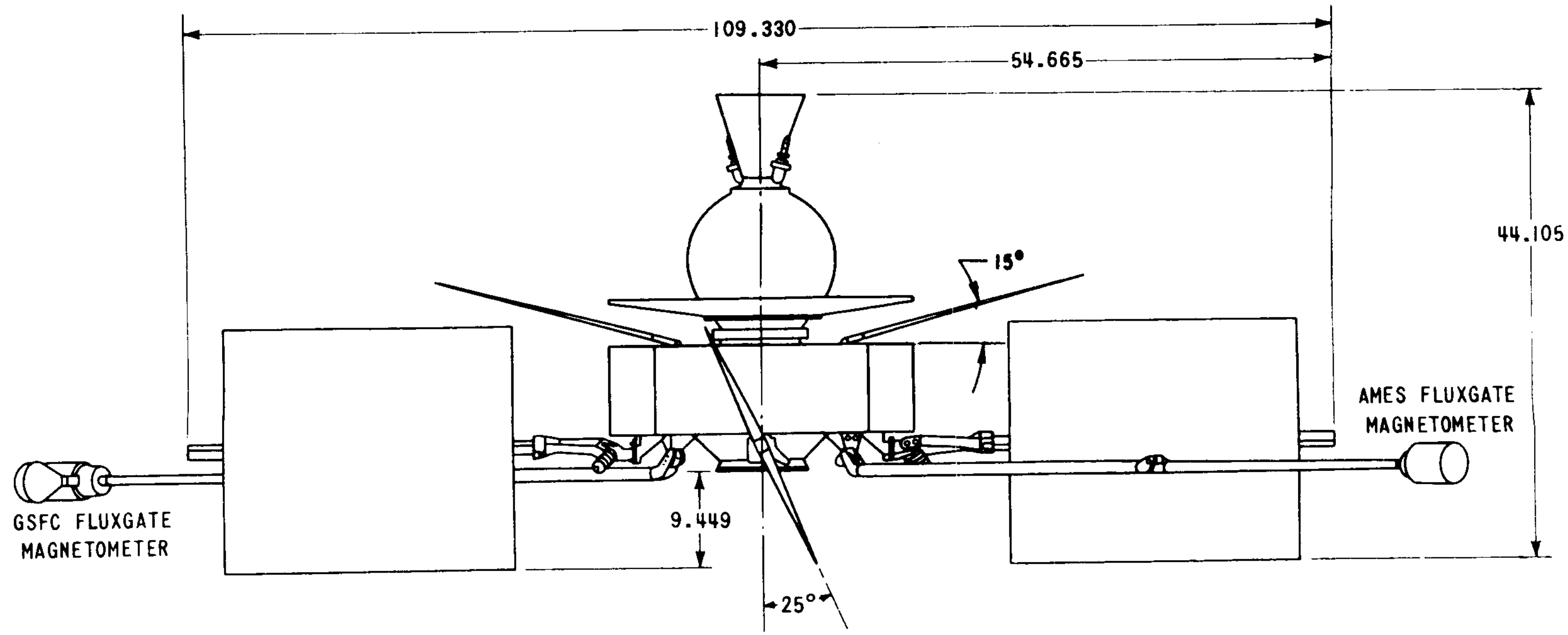
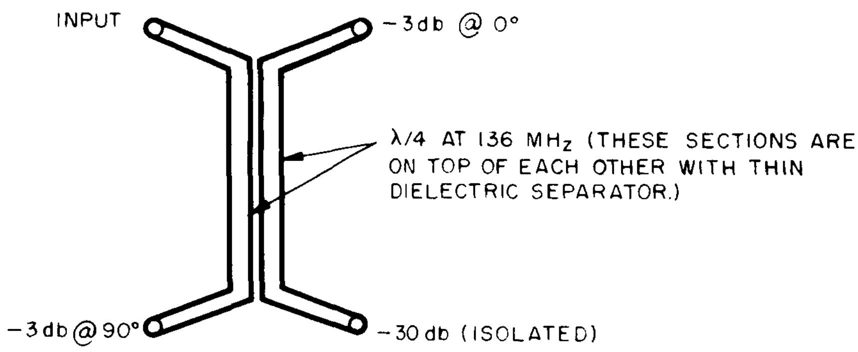


Figure 9 (Cont'd)–Explorer 35 Satellite



NOTES:

1. COUPLER IS FOLDED INTO 3" X 3" X 1/8" PACKAGE (EXCLUDING CONNECTORS)
2. DEVICE IS RECIPROCAL. ANY SET OF INPUTS AND OUTPUTS MAY BE USED.

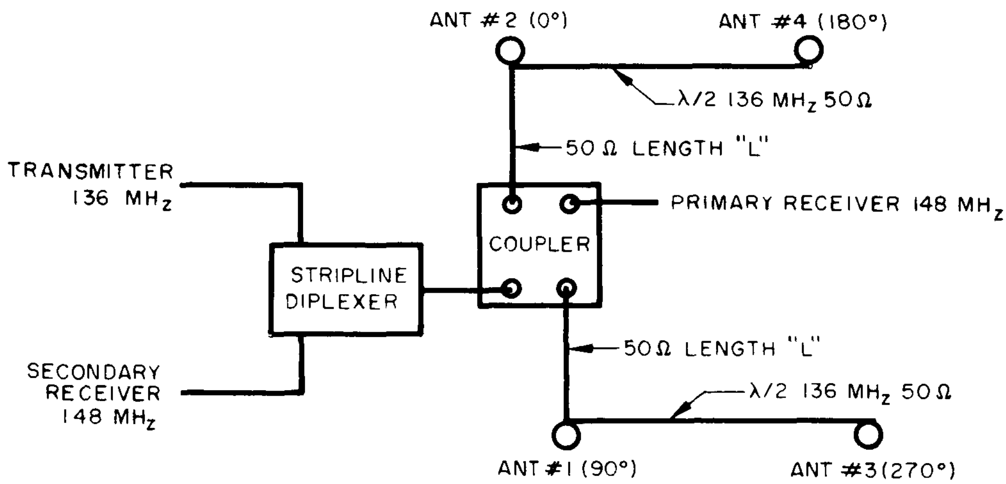


Figure 10–Explorer 35 Feed System

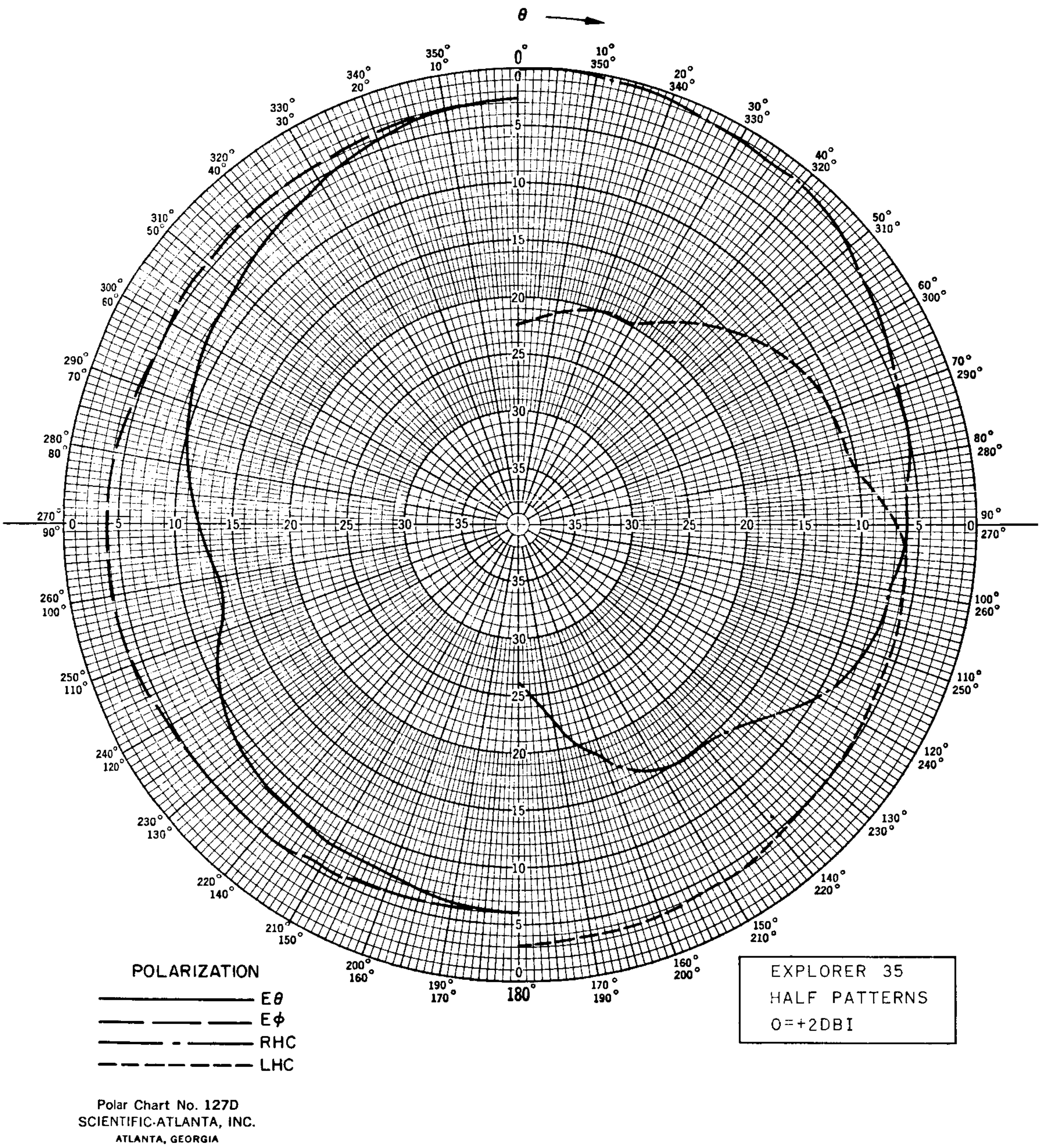


Figure 11—Explorer 35 Antenna Pattern

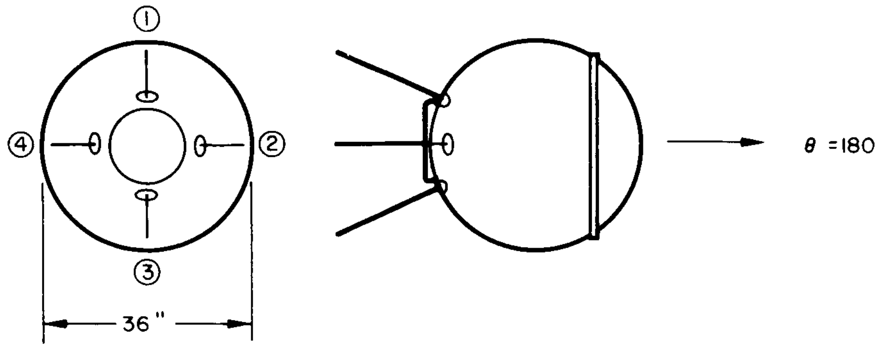
AE-B (Explorer 32) Figure 12

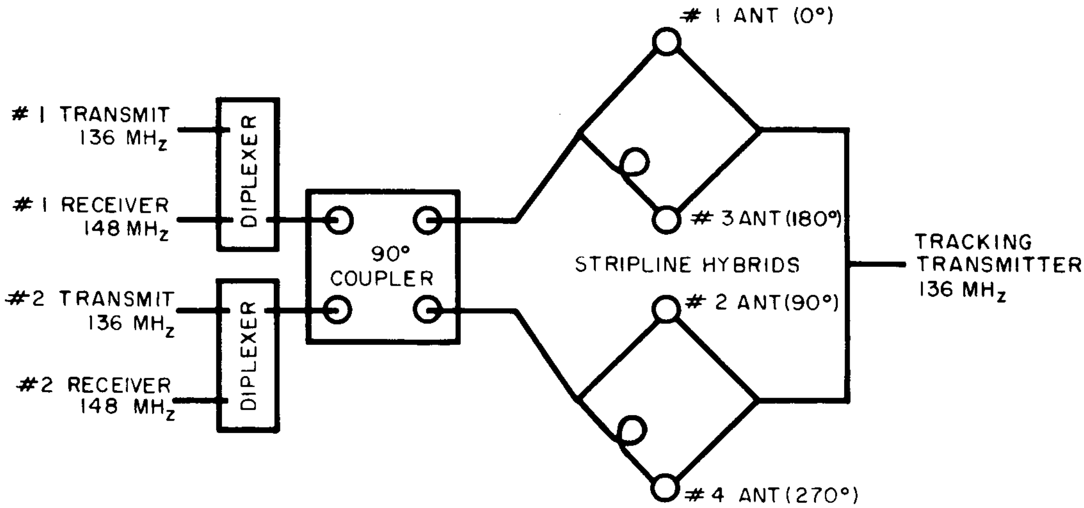
Antenna:	Canted turnstile
d:	15"
α:	65°
Feed:	Stripline coupler-hybrid combination
Phasing:	Provided by feed
Frequency:	Transmit 136 MHz
	Receive 148 MHz
Performance:	Omnidirectional pattern. Both senses of circular polarization are transmitted and received. Provision is also made for linear polarization of a tracking transmitter. (Figure 13).

The 90° coupler has an advantage over the coaxial hybrid in that the necessary phase shift needed to produce circular polarization is furnished as a function of the coupler rather than by a fixed coaxial line length. It thereby provides a wideband 90° rather than at a single frequency. The half-wavelength cables connecting opposite pairs of antennas were still frequency sensitive. The AE-B used a combination coupler-hybrid to assure correct phase shifts at both frequencies. Since the antennas are fed singly instead of in pairs, the antennas are matched to 50 ohms. This spacecraft required the use of the single antenna system by three transmitters and two receivers. Coaxial switching was not desired. The design of the coupler-hybrid permitted the use of these instruments and provided satisfactory antenna pattern coverage. The primary transmitters and receivers had the usual canted turnstile type pattern. The tracking transmitter had a dipole type pattern parallel to the spin axis.

Matching of Antennas

The near quarterwave monopole, fed as one half of an opposed pair of antennas has an input impedance of the order of 80 ±45°. It is therefore possible to match the impedance to either 50 or 100 ohms depending on system requirements. Usually a plot of impedance vs length of the antennas in the proper structure is made and a convenient value of length selected to facilitate matching. The matching components (all reactive) are installed in a small chamber in the base of each antenna. This permits the rest of the feed system to operate in a low loss balanced condition.





NOTES:
1. COUPLER & HYBRIDS FORM ONE PACKAGE 5" X 5" X 1/2" (EXCLUDING CONNECTORS)
2. ANTENNAS WERE FED WITH FOUR EQUAL LENGTH CABLES.

Figure 12–Explorer 32 Satellite

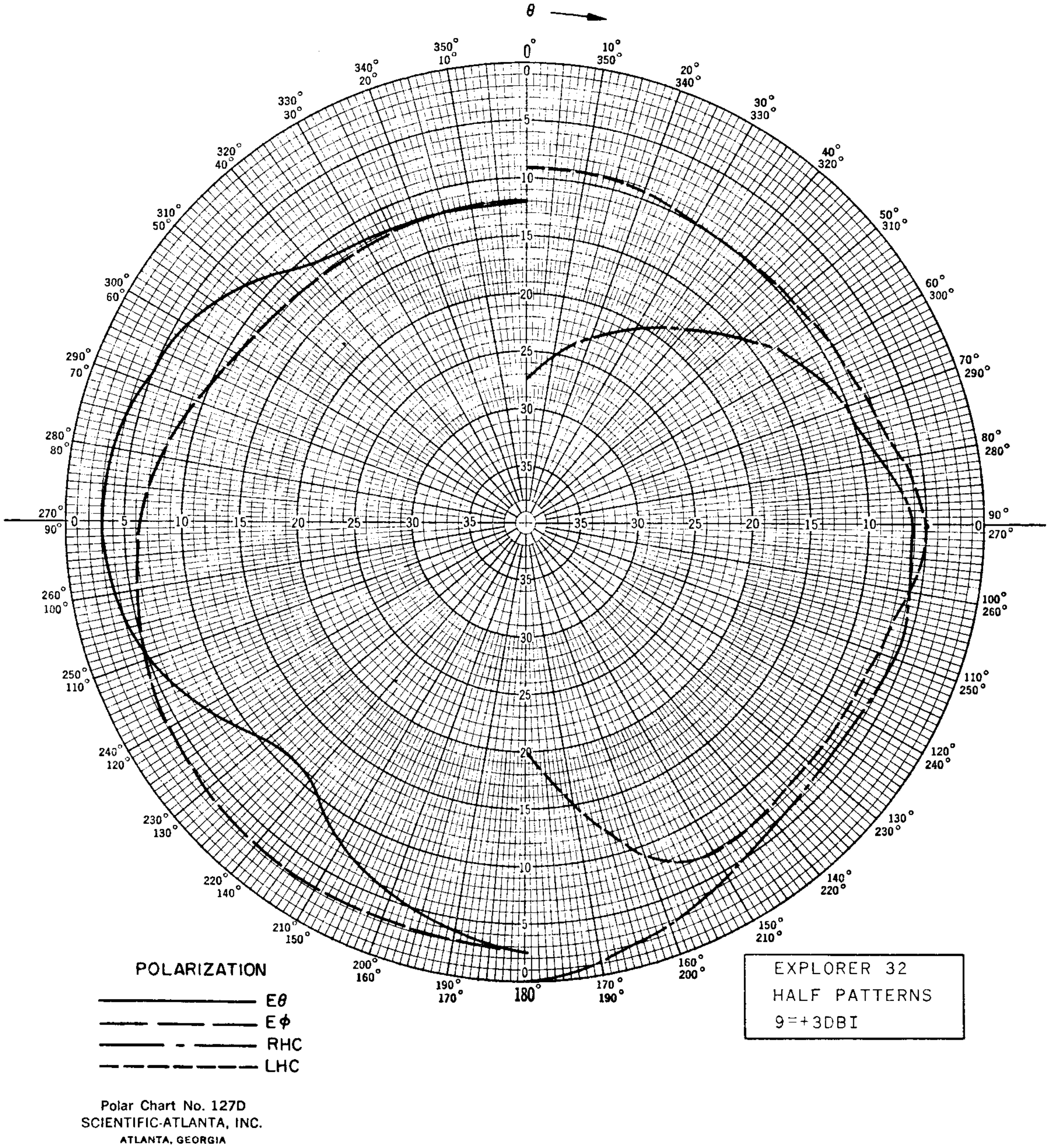


Figure 13—Explorer 32 Antenna Pattern

Feed System Conclusions

The two feed systems which offer the best performance for the turnstile system are the 90° coupler and the coupler hybrid combination.

The 90° coupler provides proper phase shift at more than one frequency and good low loss balanced power distribution. The phasing cables between antennas are still frequency sensitive. For the 10% band worked at Goddard this phase error is not prohibitive but it could be for larger bands.

The coupler-hybrid combination offers a complete 50 ohm system which is wide band. The various phase shifts are all functions of the device and are not frequency sensitive over the device bandwidth. Since there are more stripline components the system is larger and heavier and system loss will be slightly increased.

APPENDIX

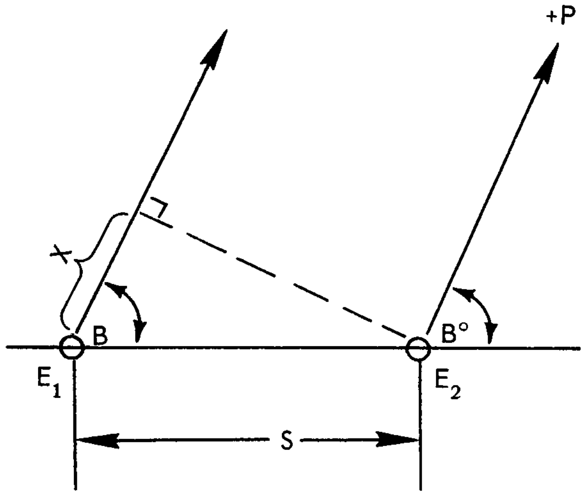
E_1, E_2 are antenna elements radiating in phase.

P is a point of reference sufficiently distant that the rays from the two antennas are considered to arrive parallel to each other.

S is the separation of the antennas measured in electrical degrees.

B is the angle between ray path and plane containing elements.

X is path length difference between the two rays.



In this system the path length difference may be expressed as a differential phase shift given by

$$X^\circ = S^\circ \cos B$$

Since Cos B will vary from 1 to 0 as B varies from 0° to 90° it is seen that differential phase shift is directly related to the angle B. If S is small the differential phase shift will be small, but for large S will vary periodically. When this phase shift is n(360°) the signals will be in phase and add (pattern maxima) when the differential shift is n(180°) the signals will cancel (pattern minima).

Example: let $S = 2\lambda = 720°$

B°	Cos B	X°	Result
0	1	720°	Max.
41.4	.75	540°	Min.
60	.5	360°	Max.
75.5	.25	180°	Min.
90	0	0°	Max.

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